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The Isothermal Layer of the Atmosphere and Atmospheric Radiation. By E. Gold, M.A.

[*Abstract of a paper in the Proceedings of the Royal Society, A., vol. lxxxii. pp.* 43–70.]

The investigation of the upper air by means of kites and balloons carrying self-recording instruments has furnished values for the temperature and the temperature gradient up to heights of 20–30 km.

The most remarkable phenomenon revealed is the comparatively sudden cessation of the fall of temperature at a height varying with the time, the type of pressure distribution, and the latitude. Above this height, which may be regarded as the height of an irregular but roughly horizontal surface dividing the atmosphere into two regions, the temperature at any time varies very little in a vertical direction, showing on the average a slight tendency to increase. This comparative absence of regular vertical temperature variation in the upper region led to the name "Isothermal Layer or Region," to distinguish it from the lower atmosphere, in which the average vertical variation is about 6° C. per km.*

The height at which the change in the temperature gradient takes place will be denoted by H_c, and the temperature by T_c.

The average value of H_c for places in Europe near lat. 50° is

* The rate of fall from the Earth's surface up to 3 km. is about 5° C. per km. on the average, but it is not regular, and occasions frequently occur, especially in winter, when the temperature increases with the height. Thus on November 7, 1906, the surface temperature at Lindenberg (122 m.) by Berlin was 7° C., while at 500 m. it was 17° C., and at 1000 m. 15° C.; and again, on December 23, 1906, the surface temperature was −14° C., at 1000 m. it was +1° C., and at 2000 m. −3° C.

11 km., and of T_c is -55° C. The annual variation in H_c is about 2·5 km., and in T_c is 10° C. On the whole, H_c is greatest in autumn and T_c in summer. There is practically no variation with latitude for places in Europe between lat. 45°–55°, but H_c increases and T_c decreases considerably near the equator, where H_c is greater than 15 km., and T_c less than -70° C.

The value of H_c in Europe is about 10 km. over regions of low pressure, and 12·5 km. over regions of high pressure.

It is clear that there cannot be convection currents to any marked extent in the isothermal region, and it will be shown that the thermal conditions in the upper air prevent persistent convection there.

Let the average intensity of radiation of wave-length λ crossing unit area of a horizontal plane be

P_λ from the atmosphere below the plane,
Q_λ „ „ above the plane,
G_λ from the Earth,
V_λ from the Sun.

Further, let the absorption of radiation by a horizontal layer be

X_λ from the atmosphere above the layer,
Y_λ „ „ below the layer,
E_λ' from the Earth.
S_λ' from the Sun,

and let the radiation from the layer be K_λ. Then convection is possible only if

$$\int (P_\lambda + Y_\lambda) d\lambda > \int (Q_\lambda + G_\lambda) d\lambda$$

everywhere, and

$$\int (X_\lambda + Y_\lambda + E_\lambda' + S_\lambda') d\lambda < \int K_\lambda d\lambda$$

in the upper layers of the convective system. These quantities can be expressed in terms of the absorbing power, b, of the atmosphere and its temperature.

The experiments of Ångström,* Paschen,† Rubens, and Aschkinass ‡ and others have shown that the constituents of the atmosphere, CO_2 and water-vapour chiefly, absorb and radiate through a very considerable portion of the spectrum of radiation at terrestrial temperatures. In fact, with the possible exception of the regions 8–9μ, 10–12μ, there is absorption practically throughout the spectrum, although, of course, the intensity is not everywhere the same.

Now in a dry atmosphere in convective equilibrium the temperature $T \propto p^n$ nearly where $n = 1/3{\cdot}5$ and p is the pressure;

* *Öfversigt af K. Vet. Akad.*, 1890, 1901.
† *Ann. der Physik.*, 1894.
‡ *Astrophysical Jour.*, 1898.

also if I refers to a full radiator at temperature T, $I_\lambda \propto T^5$ near the wave-lengths of maximum radiation and $\int I_\lambda d\lambda \propto T^4$, so that we may put as an approximation $I \propto p$, corresponding to a temperature diminution rather slower than that for dry air in the convective state, and therefore very nearly the same as the actual temperature diminution in the lower region of the atmosphere.

If b is constant, *i.e.* if the constitution of the atmosphere is the same throughout, and if the condition $I \propto p$ holds throughout, the value of $\int (X_\lambda + Y_\lambda + E_\lambda' - K_\lambda) d\lambda$, which represents the excess of absorption over radiation, is, for a layer extending from p' to p_1,

$$\frac{2\pi I_0}{p_0} \int_1^\infty bx^{-4} dx \left[e^{-b(p_1+p')x} - e^{-bp_1 x} \right] \left[e^{bp'x} - e^{bp_1 x} \right].$$

It follows that, apart from solar radiation, any layer for which $p_1 + p' < p_0$ absorbs more than it radiates. Thus every layer above the height corresponding to a pressure $\frac{1}{2}p_0$ would rise in temperature, and the postulated convective state could not be maintained to heights greater than this. In the Earth's atmosphere there will be actually a decrease in the value of b with increasing height, owing to the decrease in the proportional amount of water-vapour present. This may be represented approximately by writing $b = a/(q-p)$ where a and q are constants.

The value of $X_\lambda + Y_\lambda + E_\lambda' - K_\lambda$ for a layer extending from the outer limit to a place at pressure p' is found to be always positive so long as $p' < \frac{1}{2}q$. But $q > p_0$, and therefore any layer starting from the outer limit and not including more than half the atmosphere is certainly absorbing more than it would radiate if it were in the convective state. Since the radiating power is greatest in the lower layers of such a region where the temperature is highest, it follows that the radiation from the region will be greater than if it were isothermal throughout at the temperature corresponding to a pressure $\frac{1}{2}p'$. Hence if the outer region of the Earth's atmosphere, starting from a pressure p, is isothermal, its temperature must be greater than that given by the equation

$$T^4 = \tfrac{1}{2} \frac{p}{p_0} T_0^4,$$

where p_0, T_0 are the values of p, T at the Earth's surface.

The values of q and a will vary for different wave-lengths, but in order to obtain approximate results we may take mean values for these quantities. Two values are taken for q, viz. $\frac{2}{3}p_0$, $\frac{5}{4}p_0$, corresponding to a diminution in the absorbing power more rapid and less rapid respectively than the decrease in the proportion of water-vapour present. The values of a are obtained on the assumptions

(i) That 25 per cent. of the radiation is transmitted freely and 50 per cent. is absorbed in vertical transmission through the atmosphere.

(ii) That 20 per cent. of the radiation is absorbed by a path of 100^m at the Earth's surface, and the absorption takes place throughout the spectrum.

The values of a corresponding to $q = \frac{9}{8} p_0$ are 0·5, 2·0

and corresponding to $q = \frac{5}{4} p_0$ are 0·68, 4·0.

If the values of $\int P_\lambda d\lambda$, etc. are denoted by P, Q, the following table gives the values of P, Q at different levels, (a) for I constant, (b) for $I \propto p$ corresponding to the values of a 0·5, 2.0; 0·68, 4·0.

At $p = 0$.

(a) P = 0.
Q = 0·61πI, πI; 0·61πI, πI.

(b) P = 0.
Q = 0·32πI, 0·26πI; 0·27πI, 0·18πI.

At $p = \frac{1}{4} p_0$.

(a) P = 0·15πI, 0·56πI; 0·18πI, 0·75πI.
Q = 0·58πI, 0·99πI; 0·57πI, 1·00πI.

(b) P = 0·015πI, 0·08πI; 0·02πI, 0·09πI.
Q = 0·37πI, 0·46πI; 0·34πI, 0·39πI.

At $p = \frac{1}{2} p_0$.

(a) P = 0·30πI, 0·83πI; 0·33πI, 0·94πI.
Q = 0·54πI, 0·98πI; 0·52πI, 1·00πI.

(b) P = 0·10πI, 0·30πI; 0·15πI, 0·34πI.
Q = 0·40πI, 0·63πI; 0·38πI, 0·60πI.

At $p = p_0$.

(a) P = 0·61πI, πI; 0·61πI, πI.
Q = 0.

(b) P = 0·49πI, 0·93πI; 0·47πI, 0·95πI.
Q = 0.

The total absorption apart from that of solar radiation in the layer above $p = \frac{1}{2} p_0$ is

0·23πI, 0·55πI; 0·28πI, 0·57πI,

and the total radiation is

0·18πI, 0·46πI; 0·23πI, 0·49πI.

The radiation is therefore less than the absorption.

If the layer above $p = \frac{1}{2} p_0$ were isothermal, the absorption in it would be unchanged, but the total radiation would be

0·30πI, 0·83πI; 0·33πI, 0·94πI.

The radiation would therefore exceed the absorption very considerably and the temperature would necessarily fall. It is not

possible then to have so large a portion of the atmosphere isothermal. The total absorption, excluding that of solar radiation, in the layer above $p = \frac{1}{4}p_0$ is

$$0{\cdot}10\pi I,\ 0.27\pi I\ ;\ 0{\cdot}13\pi I,\ 0{\cdot}32\pi I.$$

The radiation from the layer if it were isothermal would be

$$0{\cdot}07\pi I,\ 0{\cdot}28\pi I\ ;\ 0{\cdot}09\pi I,\ 0{\cdot}37\pi I,$$

and does not exceed the absorption.

Therefore if the outer region is isothermal, the isothermal state must extend at least until the layer $p = \frac{1}{4}p_0$ is reached, *i.e.* the convective state cannot exist to a height greater than that for which $p = \frac{1}{4}p_0$, and from above it must extend to a height greater than that for which $p = \frac{1}{2}p_0$.

The absorption in the layer p_0 to $\frac{1}{4}p_0$ is

$$0{\cdot}61\pi I,\ 1{\cdot}13\pi I\ ;\ 0{\cdot}61\pi I,\ 1{\cdot}19\pi I.$$

The radiation from it is

$$0{\cdot}85\pi I,\ 1{\cdot}39\pi I\ ;\ 0{\cdot}81\pi I,\ 1{\cdot}34\pi I.$$

The radiation therefore exceeds the absorption by

$$0{\cdot}24\pi I,\ 0{\cdot}26\pi I\ ;\ 0{\cdot}20\pi I,\ 0{\cdot}15\pi I,$$

and this excess must be made up by absorption of solar radiation and by convection of heat from the Earth's surface either in the form of warmed air or water-vapour.

If solar radiation and convection are absent and the temperature of the layer falls uniformly, the rate of fall will be about 1° C. in twenty-four hours.

The outward radiation across the outer limit of the atmosphere if the region above $p = \frac{1}{4}p_0$ is isothermal is

$$0{\cdot}73\pi I,\ 0{\cdot}32\pi I\ ;\ 0{\cdot}68\pi I,\ 0{\cdot}28\pi I.$$

The difference between the incident and reflected solar radiation is, if the diffused solar radiation is 40 per cent. and the reflection at the Earth's surface is 10 per cent., nearly 0·72 S, where S is the average intensity of solar radiation outside the atmosphere. If the Earth is covered with cloud, which reflects 65 per cent. of the incident radiation according to Abbott and Fowle, and the diffused radiation to the cloud-level is 16 per cent., the average value of the difference is 0·41 S. The actual value probably lies about midway between these two estimates, *i.e.* is about 0·575. This must be balanced by the outward radiation across the upper limit of the atmosphere ; and since $S \geqslant \pi I$, the results indicate that the assumption (i) regarding the absorbing power of the atmosphere is the more correct.

The problem of the influence of the distribution of temperature on astronomical refraction is outside the scope of the paper. But

it may be pointed out (i) that the variation of H_0, T_0 with latitude makes the surfaces of equal density in the upper air more nearly parallel to the Earth's surface than they would be with a uniform gradient of temperature; (ii) that the density never increases with the height, and no anomalies, due to an increase in refraction with height, can arise; (iii) that the mean temperature of the air is, in general, higher when the surface temperature is low, and lower when the surface temperature is high, than the observations at ground-level would indicate.

On the origin of certain lines in the Spectrum of ϵ Orionis (Alnitam). By Sir Norman Lockyer, K.C.B., F.R.S., F. E. Baxandall and C. P. Butler. [Printed *in extenso* in *Proc. Roy. Soc.*, A. 557.]

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The star ϵ Orionis (Alnitam) is of great importance as offering a possible transition stage between the helium and bright line stars, and the only outstanding lines of unknown origin were those at 4097, 4379·8, and a conspicuous double at $\begin{cases} 4647{\cdot}6. \\ 4650{\cdot}8. \end{cases}$

In the case of 4097, the clue to the identification was obtained from a spark spectrum of chromium, showing local intensifications of certain lines at one of the poles. Two of these lines were found to be the previously-known silicon (IV) lines, 4089, 4116, probably present as impurities in the fused chromium, while one of the remaining two lines was found to coincide with the ϵ Orionis line at 4097. These four lines are shown under various conditions in the plate, indicating the steps taken in tracing their origin to nitrogen.

In the spectrum of nitrogen, under the special conditions which gave the above lines at 4097, 4103, another line was found at 4379·8, which was greatly strengthened in comparison with its intensity in the ordinary spark, and this line coincides with the unknown line in ϵ Orionis.

During the work on the above lines, one of the photographs taken of an alcohol spectrum showed abnormal intensifications on either side of the oxygen line 4649·2, suggesting the presence of a new double. The wave-lengths of the components of this double were determined as 4647·6, 4650·8, coinciding with the wave-lengths of the components of the strong double in ϵ Orionis. By a series of comparison photographs of spectra under varied conditions, the origin of the double was traced to carbon, and one of the strips of the plate (carbon sparks in hydrogen) shows it quite isolated as it appears in the stellar spectrum. Further evidence of the validity of the identification is afforded by the peculiar nature of the components of the double.

Further notes on Latitude Drift in Sun-spots. Papers of the I.U.S.R. Computing Bureau. No. V.

F. J. M. Stratton, M.A.

In the second of this series of papers (*M.N.*, vol. lxviii., No. 8) the following statement is made : "Nor does an examination of the spot returns tabulated by Father Cortie (*M.N.*, vol. lx.) give much support to the hypothesis of a physical drift." The analysis of the material for this statement is given below in §§ 2 and 3. Some further notes are added concerning the different behaviour of different latitude zones. The reason for the appearance of these notes at this present juncture is not that any definite conclusions have been reached, but rather that other workers are examining the question, and that, on the whole, it is advisable to avoid unnecessary repetition of work.

1. *Spot returns.*—Father Cortie's list of spot repetitions covers the period 1881–1899. He identifies 112 spots as returning, many of them more than once. For 25 of these spots the identity of the returning spot did not seem certain enough to justify its use in the discussion of the drift of the spot during a complete rotation of the Sun. [For convenience of writing, we shall call such a drift by the loose term *monthly drift.*] The remaining 87 spots gave by repeated returns 186 monthly drifts in all to be analysed. Of these drifts 32 were more than 2° in amount, and were rejected in a second analysis as unduly affecting the results. The remaining monthly drifts were then analysed from various points of view.

2. *Analysis by Latitude Zones.*—First of all, a division into latitude zones was made, and the following table of mean drifts was obtained.

TABLE I.

Latitude Zone.	Excluding Drifts $>2°$.	All Spots.	Latitude Zone.	Excluding Drifts $>2°$.	All Spots.
$-30°$	-34_1	-34_1	0°		
-25	-16_3	-68_5	+ 5	-55_1	-94_2
-20	-1_{15}	-1_{15}	+10	-56_6	-68_6
-15	-32_{14}	-52_{18}	+15	-57_{17}	-18_{18}
-10	$+31_{29}$	$+22_{36}$	+20	-16_{12}	-25_{16}
-5	$+23_{42}$	-5_{48}	+25	-4_{12}	-34_{19}
0	-60_1	-60_1	+30	-56_1	-56_1

The unit for the above table is 0°·01 per rotation of 25·38 days, and the suffix gives the number of spots in each zone. The positive values given for the zone $-15°$ to $-5°$ made it desirable to rearrange the latitude zone material previously discussed by Professor Turner, to test whether the latitude zone $-15°$ to $-5°$ is also shown to be singular by the motion of spots across the face of the Sun. The following table gives the mean monthly drift of Father Cortie's spots, the proportional drift between $\beta = \pm 65°$ and the observed drift for all spots between $\beta = \pm 65°$ during the epoch

1881–99 (β is the longitude before the central meridian). The simple mean is obtained by giving all the zones equal weight, the weighted mean by giving all the spots equal weight.

TABLE II.

Lat.	Mean Monthly Drift		Corresponding Drift between ± 65°.		Observed Drift between ± 65°.
	Excluding >2°.	All Spots.	Excluding >2°.	All Spots.	
−25°	-16_{29}	-27_{33}	− 6	−10	-17_{209}
−15	$+26_{71}$	$+6_{84}$	+ 9	+ 2	-30_{243}
− 5	-57_{2}	-83_{3}	−21	−30	-38_{92}
+ 5	-57_{23}	-30_{24}	−21	−11	-16_{292}
+15	-10_{24}	-30_{25}	− 4	−11	-13_{162}
+25					
Simple mean	−23	−33	− 9	−12	−23
Weighted mean	− 2	−14	− 1	− 5	−21

The last two columns are not at all alike. Various methods of treating the figures give slight mean physical drifts of the right *sign*; but not even the most favourable gives more than half the *amount* required on the hypothesis that the latitude drift observed across the face of the Sun is a steady physical drift. An assumption that the Earth influenced the spots on the visible disc, but had no effect when they were out of sight, would bring us nearer the correct amount. But it seems that for the present the idea of a physical drift must be abandoned as a complete explanation of the phenomena observed. We note, however, that Carrington (*Observations of Solar Spots*, p. 222) suggests, as indicated by his results, a feeble drift of the spots towards the equator in low latitudes; the analysis of the monthly drifts fully endorses this suggestion for the two zones from 5° to 15° N. and S. of the equator.

3. *Analysis by Years.*—Other groupings of the monthly drifts have failed to yield results of any interest. Grouped in years they are as follows:—

TABLE III.

Year.	Mean Monthly Drift		Year.	Mean Monthly Drift	
	Excluding Values >2°.	All Spots.		Excluding Values >2°.	All Spots.
1881	$+6_{4}$	$+6_{4}$	1891	-2_{6}	-2_{9}
1882	-29_{7}	-74_{8}	1892	-61_{10}	-67_{14}
1883	-76_{10}	-76_{10}	1893	$+19_{18}$	$+49_{20}$
1884	$+45_{8}$	$+17_{9}$	1894	-42_{13}	-70_{18}
1885	-36_{11}	$+16_{15}$	1895	-19_{12}	-21_{13}
1886	$+9_{12}$	$+19_{15}$	1896	-66_{4}	-104_{5}
1887	$+73_{5}$	$+75_{4}$	1897	-24_{10}	$+9_{14}$
1888	$+43_{1}$	$+180_{2}$	1898	$+34_{7}$	$+69_{8}$
1889	-31_{5}	-89_{7}	1899	-10_{3}	-10_{3}
1890	$+31_{9}$	$+10_{12}$			

It will be noticed that no connection between these results and the mean drifts given in *M.N.*, lxviii. p. 612, can be traced, which

adds force to the suggestion there made that the drift is not entirely a physical drift, but is in some part illusory. Arrangement of the monthly drifts according to calendar months failed to lead to results of any interest.

4. *Long-period Changes in Latitude Drift.*—As not much more information was to be obtained from the monthly drifts, and as it was desirable to test some of the points raised by Professor Turner in the earlier papers of this series by an independent discussion of the data, the next piece of work attempted was an examination of the difference of latitude drift in the three zones $-20°$ to $-10°$, $-10°$ to $+10°$, and $+10°$ to $+20°$ for all spots crossing the meridans $\beta = \pm 35°$. Keeping the three zones distinct, and arranging the drifts in years, the following results were obtained: the unit is $0.°01$ drift between $\beta = \pm 35°$.

TABLE IV.

	Mean Drift			
Lat. Zone.	$-20°$ to $-10°$.	$-10°$ to $+10°$.	$+10°$ to $+20°$.	$-20°$ to $+20°$.
Year.				
1874	-29_{6}	$+29_{12}$	-52_{7}	-8_{25}
1875	$+74_{6}$	$+14_{9}$	$+27_{4}$	$+36_{19}$
1876	-57_{6}	$+30_{3}$	-60_{1}	-31_{10}
1877	$+10_{2}$	$+17_{11}$	$+40_{1}$	$+17_{14}$
1878	—	$+92_{3}$	-40_{1}	$+59_{4}$
1879	—	—	—	—
1880	$+22_{10}$	—	$+8_{11}$	$+15_{21}$
1881	$+16_{12}$	$+83_{2}$	-6_{25}	$+5_{39}$
1882	$+21_{22}$	$+14_{14}$	-8_{27}	$+7_{63}$
1883	$+13_{34}$	-9_{27}	-26_{20}	-4_{81}
1884	$+41_{30}$	$+7_{49}$	$+22_{19}$	$+20_{98}$
1885	-10_{24}	$+19_{27}$	$+10_{17}$	$+4_{78}$
1886	$+2_{16}$	-10_{20}	-13_{4}	-4_{40}
1887	$+28_{4}$	$+4_{16}$	-25_{3}	$+4_{23}$
1888	-67_{2}	-11_{9}	-62_{1}	-25_{12}
1889	-75_{1}	-19_{7}	—	-39_{8}
1890	—	$+37_{2}$	-66_{2}	-10_{4}
1891	-19_{11}	—	$+2_{32}$	-3_{43}
1892	-18_{24}	-44_{16}	-29_{37}	-29_{77}
1893	-15_{50}	$+1_{37}$	-23_{37}	-12_{124}
1894	-27_{42}	-26_{45}	-19_{36}	-24_{123}
1895	-32_{29}	-17_{22}	-23_{44}	-25_{95}
1896	-16_{27}	-31_{12}	-70_{10}	-31_{49}
1897	-1_{8}	-39_{35}	-1_{5}	-24_{48}
1898	$+29_{14}$	-8_{19}	-78_{8}	-6_{41}
1899	-23_{9}	$+35_{8}$	—	$+5_{17}$
1900	$+48_{1}$	-12_{9}	—	$+16_{10}$
1901	—	$+4_{3}$	—	$+4_{3}$
1902	—	$+12_{2}$	-50_{1}	-8_{3}
1903	$+15_{7}$	—	-31_{8}	-9_{15}
1904	$+42_{19}$	$+31_{4}$	-11_{26}	$+14_{49}$
1905	-55_{30}	-63_{22}	-67_{26}	-61_{78}

The first point to be noticed is, that all the three zones show the change of sign in the mean drift already noted for the whole body of spots. This may again be emphasised by considering only the spots grouped around a maximum, when we have the following table :—

TABLE V.

Years.	−20° to −10°.	−10° to +10°.	+10° to +20°.	−20° to +20°.
1874–6	-4_{18}	$+23_{24}$	-26_{12}	$+3_{54}$
1880–6	$+14_{158}$	$+6_{129}$	-2_{123}	$+7_{410}$
1891–7	-20_{191}	-24_{167}	-16_{201}	-20_{559}
1803–5	-14_{56}	-48_{26}	-38_{60}	-30_{142}

This table, viewed along with the previous table, certainly suggests that the change in mean drift is a long-period change, with a maximum northerly drift in the neighbourhood of the 1884 maximum, and there seems to be some sign that the drift in the equatorial zone precedes in phase the drift in the other zones. A period of about fifteen years seems vaguely indicated, but so many years depend on quite a few spots for their mean drift that no reliance can be placed on this until more maxima are investigated. One further fact which seems to come from the tables above is, that the mean drift south is distinctly greater in the most northern zone. If we give each spot equal weight, the mean drifts in the three zones for the period 1874–1905 are—

−20°	−10°	+10°	+20°
−5	−8	−20	

while if we give each year equal weight, thus neglecting the extreme weight generally assigned to years of sun-spot maxima, we get the following figures

−20°	−10°	+10°	+20°
−3	+5	−23	

The zone of latitude +10° to +20° seems to differ markedly from the other two zones, and we shall see that this is the case again when the drifts are analysed in a different investigation.

5. *Annual Variation.*—If the drifts in the three zones are analysed into monthly groups we get the following table of mean drifts :—

TABLE VI.

Month.	−20° to −10°.	−10° to +10°.	+10° to +20°.	−20° to +20°.
Jan.	−2	−25	−46	−22
Feb.	−13	−11	+5	−6
Mar.	+6	+7	−5	+4
Apr.	+17	+31	−36	+7
May	−9	+10	+18	+6
June	−14	+31	−5	0
July	−2	−4	−22	−8
Aug.	−11	+1	−7	−6
Sept.	−16	−11	−16	−14
Oct.	−5	−13	−21	−14
Nov.	−12	−43	−36	−32
Dec.	−19	−35	−39	−29

The corresponding values of A, B,* which give corrections to the positions of the Sun's axis, are—

A	+4·5	+13·4	+6·5	+8·6
B	+0·4	−10·6	−5·6	−4·9

The northern zone here agrees most closely with the mean result, the other two zones differing almost equally from the mean both for A and B. It will be noticed how curiously smooth a curve is formed by plotting the monthly means for the whole series, though the three curves of which it is composed are all very irregular. All the zones show clear signs of an annual periodic change in the drift, caused, no doubt, by an error in the assumed pole of the Sun. The correction to the position of the Sun's pole already found by Professor Turner is confirmed pretty closely by this work. The only test for motion of the pole, for which the material seemed sufficient to give trustworthy results, lay in finding the position given by the two maxima of 1884 and 1894 : they are as follows—

	1880–1886.	1891–1897.
A	+7·8	+9·2
B	+0·6	−7·4

There seemed no evidence of a change in A. The change in B may be real; for the values of B given by the three zones for the two intervals 1874–1885 and 1886–1901 are—

	−20°	−10°	+10°	+20°
1874–1885	+11·9	−1·5	−3·9	
1886–1901	−2·1	−14·1	−8·1	

Thus between these two intervals, which effectively are the same as the two maxima above, B undergoes a change in value in the same direction for all three zones. The corresponding changes in value of A are much smaller in amount, and are not in the same direction for all the zones. It is impossible to say yet whether this motion of the Sun's pole is real, but if so, interesting results should be obtained, as successive sun-spot maxima give a series of carefully determined positions of the Sun's pole. We may note here again the superior steadiness of the northern zone, and the central position of its pole relative to those of the other zones.

6. *The three Latitude Zones.*—One of the three zones considered above has been shown to differ markedly from the other two in several ways. Its spots have much the greatest mean southerly drift, and at the same time they seem less liable to disturbance by irregular forces causing an apparent displacement of their centres. It seemed worth while to test further the difference between the zone and the other two, especially as this was not the zone which

* See *M.N.*, vol. lxviii. p. 610.

Carrington found to behave differently from the rest. In view of the possibility that the difference between the zones arose largely from the different times when the separate zones were crowded with spots, a discussion was made limited to months in which all three zones were represented together by spots living long enough to be dealt with. To the mean drift of each month a weight was given equal to the least number of spots in any one zone belonging to that month. The following were the resulting means:—

	−20°	−10°	+10°	+20°
1874–85	+18	+21	− 8	
1886–1901	−34	−13	−23	
1874–1901	−14	0	−17	

The usual large southerly drift for the northern zone is found for the earlier interval, but it disappears for the later interval. This particular selection of spots indeed gives the equatorial zone as the exceptional zone as regards the total mean drift: the continual steadiness of the northern zone is again marked.

Though the number of spots entering into this limited discussion is too small to furnish results of any value as to the position of the pole, we note as an interesting fact that they give to the northern zone a pole lying in position between the poles of the other two zones, and that the relative positions of the poles is the same as in the wider discussion.

7. *Longitude Zones.*—Sufficient evidence of definite difference in the latitude drift in different latitude zones has been obtained to justify a corresponding investigation of longitude zones or lunes. The obvious difficulty that the different latitude belts rotate with different angular velocities suggests that a careful investigation of this point would be very elaborate. A rough investigation was made, however, by taking the mean longitude of the spot given in the Greenwich tables—corresponding to a rotation of the Sun in 25·38 days—and grouping the latitude drifts in zones of 30° of longitude. Taking all the latitude zones together, the resulting mean drifts were as follows:—

TABLE VII.

Long.	Mean drift, 1874–1905.	Long.	Mean drift.
°–°		°–°	
0–30	-1_{94}	180–210	-5_{102}
30–60	-20_{135}	210–240	-3_{129}
60–90	-10_{118}	240–270	-3_{105}
90–120	-3_{99}	270–300	-5_{98}
120–150	-11_{98}	300–330	-10_{116}
150–180	-6_{107}	330–360	-25_{99}

There are signs that the drift south is greater on one half of the Sun's surface than on the other, the mean drift for longitude 90° to 270° being −5 and for 270° to 90° −13. An analysis of

the corresponding results in the three latitude zones shows that the mean result agrees most closely with that given by the equatorial belt. The northern and southern zones give somewhat similar results, but the phase in longitude of the maximum southern drift is different in both cases. The figures on which these necessarily somewhat vague statements are founded are given in the following table:—

TABLE VIII.

Lat. / Long.	−20° to −10°.	−10° to +10°.	+10° to +20°.
° °			
0–30	$+10_{30}$	-2_{36}	-23_{28}
30–60	-13_{49}	-19_{40}	-32_{46}
60–90	-4_{48}	-16_{40}	-9_{30}
90–120	-2_{38}	-18_{36}	$+4_{25}$
120–150	-14_{46}	$+8_{25}$	-11_{27}
150–180	-16_{37}	$+0_{33}$	-12_{37}
180–210	$+11_{21}$	$+0_{48}$	-10_{33}
210–240	$+1_{43}$	$+4_{48}$	-21_{38}
240–270	$+2_{39}$	$+10_{34}$	-14_{32}
270–300	$+5_{34}$	-11_{25}	-24_{39}
300–330	-8_{37}	-8_{37}	-10_{42}
330–360	-24_{24}	-19_{33}	-33_{42}

In connection with the above work it should be noted that Birkeland found * that the rate of rotation which gave the greatest accumulation of spots in definite longitude zones was $25^{d}{\cdot}148$. No investigation for systematic differences of latitude drift with this rate of rotation has been made. The large amount of labour involved was deemed excessive, in view of the doubtful values of the Sun's rotation in different latitudes.

8. *Short-period Changes.*—One other point only is treated in this paper. The latitude drifts have been analysed for periodic terms with periods lying between 10 and 40 days. For this purpose a small period of years grouped round a sun-spot maximum, 1892–5, was chosen. The mean drift of all spots for three days was taken as the drift for the central day, and the 3-day groups of drifts were examined graphically and analysed by Dr. Schuster's periodogram method. The graph suggested the possibility of a term of about 15 days period.

The primary analysis for periods of 12, 15, 18, 21, 24, 27, 30, 33, 36, or 39 days did not, however, strongly confirm this sugges-

* *Skrifter Vidensk. Selsk. Christiania*, 1899, p. 145.

tion, the coefficients which indicated the relative brightness, to use a spectroscopic term, of the different periods being as follows :—

TABLE IX.

Period in Days.	Brightness.	Period in Days.	Brightness.
12	0·83	27	0·23
15	1·70	30	3·55
18	2·61	33	0·94
21	0·45	36	5·55
24	0·55	39	1·62

Periods are indicated of 36 and 30 days, accompanied by periods of half their length, but the evidence is not strong enough for either period to justify anyone in claiming its existence as a proved fact.

The secondary analysis, or the search for marked periods intermediate in length between those noted above, revealed no striking result. No bright line of an intensity 5 times the mean brightness of the spectrum—to use again an optical analogy—was found. And that is generally regarded in such an investigation as the minimum brightness corresponding to a trustworthy period. Amongst the periods suggested by the brightest lines were two of 27·68 days and 33·92 days, which I mention here, as corresponding periods of half their length were also indicated. On the whole, however, it must be said that this search for short-period drifts does not encourage one to hope that in them lies the key to the puzzle presented by the latitude drifts of sun-spots.

On the Accuracy of the Alexandrian and Rhodian Eclipse Magnitudes. By J. K. Fotheringham, M.A., D.Litt.

(*Communicated by Professor H. H. Turner, D.Sc., F.R.S.*)

Mr. Cowell, in his last paper on Ancient Eclipses, *M.N.*, lxix. pp. 617, 618, shows that the eclipse of Hipparchus cannot be identified with any except that of −128 November 20 unless a large error—in the case of Mr. Cowell's formulæ, three-quarters of a digit—is assumed in the observed magnitude at Alexandria. Mr. Cowell qualifies this, however, by a reminder "that any formulæ whatever lead to the conclusion that in lunar eclipses magnitudes are occasionally a digit wrong; and further" (though to this Mr. Cowell does not agree), "that Professor Newcomb has stated that the probable error of a magnitude of a lunar eclipse is more than one-tenth part of the Moon's diameter (*M.N.*, lxvi. p. 472)."

There are in Ptolemy two groups of lunar eclipse observations with recorded magnitudes less than totality—(1) a Babylonian group, of dates ranging from −719 to −490; (2) an Alexandrian

and Rhodian group, ranging from −173 to +136. The advance of astronomical science in the interval between these two groups was enormous, and there is reason to believe that there was a corresponding increase in the accuracy of observations. That this was so in the case of planetary observations is made abundantly clear in Kugler's *Sternkunde und Sterndienst in Babel.* It would be impossible to dispute the accuracy of Mr. Cowell's statement so far as the early Babylonian eclipse observations go, but I have thought it advisable to make a separate study of the Alexandrian and Rhodian lunar eclipses before assuming the possibility of a large error in the Alexandrian solar eclipse observation recorded by Hipparchus.

As long ago as 1851 Zech,* working with Hansen's elements for the Sun and Airy's corrections to Damoiseau's tables of the Moon, found for the five Alexandrian and Rhodian eclipses recorded in Ptolemy the following magnitudes:—

Date.	Observed Magnitude.	Tabular Magnitude.	Observed *minus* Tabular Magnitude.
−173 Apr. 30	7 digits or 0·583	0·604	−0·021
−140 Jan. 27	3 digits or 0·250	0·239	+0·011
+125 Apr. 5	$\frac{1}{6}$ or 0·167	0·163	+0·004
+134 Oct. 20	$\frac{5}{6}$ or 0·833	0·812	+0·021
+136 Mar. 5	$\frac{1}{2}$ or 0·500	0·457	+0·043

It will be observed that the largest difference between observed and tabular magnitudes here amounts to 0·043, or about half a digit. As the observations in question were only made to the nearest digit, this means that they were quite accurate within the limits aimed at.

Zech, who did not call attention to the superior accuracy of the Alexandrian and Rhodian as compared with the Babylonian observations, attempted to obtain corrections from the two groups combined, but the result did not differ materially from that which he had obtained with Airy's corrections.

More recent formulæ have shown greater discrepancies between the observed and tabular magnitudes of these eclipses, but it would be easy to find small corrections to the received values which would give a result which would accord as well as Zech's with the ancient observations.

I take as a basis of calculation the table given by Mr. Cowell in *M.N.*, lxvi. p. 527. It is necessary to make one correction in the "observed magnitudes" there given. Mr. Cowell, copying an error of Newcomb's,† has given [0·33] instead of 0·83 as the observed magnitude of the eclipse of +134 Oct. 20. Mr. Cowell's

* *Preisschrift von der fürstlich jablonowski'schen Gesellschaft zu Leipzig*, (1851).

† Ptolemy, *Math. Syn.*, iv. 6 (ed. Heiberg [1898], i. p. 315), reads τὸ $\angle'$ καὶ γ′ τῆς διαμέτρου, *i.e.* $\frac{1}{2}$ and $\frac{1}{3}$ ($=\frac{5}{6}$) of the diameter. Newcomb, *Researches on the Motion of the Moon*, p. 40, has clearly overlooked the first fraction, and translates "one-third of the diameter." It is curious that Professor Ginzel, *Spezieller Kanon der Finsternisse*, pp. 232, 234, has also mistranslated this phrase.

"Observed *minus* tabular magnitude, with allowance for increment of Earth's shadow," may then be corrected for any value of the secular acceleration of F – D (angular distance of Sun from node) by applying the factor $T^2 \div 21400$, thus reversing the process given by Mr. Cowell in *M.N.*, lxvi. p. 531. In order to satisfy the eclipses as fully as Zech has done, it will be necessary to assume an empirical correction of + 1″ or + 2″ to the theoretical value of the secular acceleration of F – D, instead of Mr. Cowell's correction of + 4″·1.

First, correcting the error in the observed magnitude of the eclipse of + 134 Oct. 20, I obtain with Mr Cowell's values :—

Ref. No.	Observed Magnitude.	Tabular Magnitude	Observed *minus* Tabular Magnitude.		Observed *minus* Tabular Magnitude with allowance for increment of Earth's shadow.		Corresponding corrections to assumed secular acceleration.	
			(*a*)	(*b*)	(*a*)	(*b*)	″	″
18	0·83	0·78	+0·05		+0·03		−2.7	

Applying the corrections suggested, I obtain for the five eclipses—

Ref. No.	Date.	Observed *minus* Tabular Magnitude with allowance for increment of Earth's shadow	
		with empirical acceleration of 1″.	with empirical acceleration of 2″.
14	−173 Apr. 30	−0·03	−0·01
15	−140 Jan. 27	+0·02	+0·03
16	+125 Apr. 5	+0·02	+0·01
18	+134 Oct. 20	−0·01	0·00
19	+136 Mar. 5	+0·04	+0·03

It will be observed that an empirical acceleration of 1″ agrees with the suggestion that I made in *M.N.*, lxix. p. 469.

The corrections to Mr. Cowell's assumed secular acceleration arising from the five eclipses are—

Ref. No.	Correction.
	″
14	−1·6
15	−4·0
16	−1·5
18	−2·7
19	0·0

If these instances are too few to form the basis of any certain conclusion, they at least suggest that the true value is to be found somewhere between Mr. Cowell's assumed value and the theoretical value, which, as stated above, is 4″·1 less than his. Altogether, while it cannot be proved that there are not large errors in the Alexandrian and Rhodian lunar eclipse magnitudes, it is possible to hold that each is correct to the nearest digit; and if the lunar eclipse magnitudes attain to so high a degree of accuracy, it is improbable that there is a large error in the one Alexandrian solar eclipse magnitude preserved to us.

1909 *August* 14.

Note on Mr. Nevill's Discussion of the Long-period Terms in the Moon's Longitude. By J. K. Fotheringham, M.A., D.Litt.

(Communicated by P. H. Cowell, M.A., F.R.S.)

In *Monthly Notices*, lxvi. pp. 264–302, Mr. Nevill discusses the correction to Hansen's *Tables de la Lune* as deduced by Mr. Cowell. A portion of Mr. Nevill's paper (pp. 275–283, 298–302) deals with Mr. Cowell's corrections to the secular terms and empirical inequalities of very long period, and suggests certain supplementary terms. It is with this portion only that I am concerned. I venture to suggest that Mr. Nevill has misinterpreted Mr. Cowell's meaning, and has in consequence drawn conclusions which, whether correct or not, are really independent of Mr. Cowell's method of investigation.

In some measure this is the result of a small error in one of Mr. Cowell's papers. In *M.N.*, lxv. p. 35, Mr. Cowell states that the terms

$$-4''\cdot3+15''\cdot0\cos 45^\circ t-9''\cdot7\sin 45^\circ t$$

may be replaced by

$$-4''\cdot3+9''\cdot8\cos 50^\circ t+5''\cdot2-4''\cdot4\mathrm{T}^2$$
$$-7''\cdot2\sin 50^\circ t-3''\cdot0\mathrm{T},$$

where T is measured in centuries and t is measured in units of 40×400 lunar days, or forty-five years nearly from the middle of Mr. Cowell's sixty-seventh period of analysis, or the year 1826·1.

In *M.N.*, lxv. p. 273, Mr. Cowell determines to assume such a period for his long-period empirical term as will make the secular acceleration equal to its theoretical value. He therefore adopts, as a correction to the mean longitude resulting from Newcomb's corrections to Hansen,

$$-4''\cdot3+\tfrac{1}{2}\{+5''\cdot2-3''\cdot0\mathrm{T}-4''\cdot4\mathrm{T}^2\}$$

and applies this directly to Newcomb's mean longitude, reduced to epoch 1800·0. It is clear that Mr. Cowell has here neglected to reduce his correction to Newcomb's epoch. Properly reduced, the correction would be

$$-4''\cdot3+\tfrac{1}{2}\{+5''\cdot7-0''\cdot7\mathrm{T}-4''\cdot4\mathrm{T}^2\}.$$

This error does not affect Mr. Cowell's discussion of the long-period empirical term, which was already complete before the error was made. It does affect the values which Mr. Cowell found for the Moon's mean longitude and mean motion at epoch, but the error is unimportant, because these values depended on the adoption of the theoretical value for secular acceleration, and there can be no doubt that this value requires a large empirical increment.

Unfortunately Mr. Nevill, in his discussion of Mr. Cowell's empirical terms, took the resultant corrections to mean longitude

and mean motion at epoch from this passage, and not from the correct statement quoted above from *M.N.*, lxv. p. 35, so that his discussion is vitiated to this extent.

In *M.N.*, lxvi. pp. 275, 276, Mr. Nevill formulates Mr. Cowell's values for the corrections to Hansen's secular terms, and also the values adopted by Mr. Cowell for the terms of very long period which should be included in the tables. These, with the substitution of the strict theoretical values of the Venus terms for the value used by Mr. Cowell, make what Mr. Nevill calls "Cowell Solution I"; it appears to be a fair representation of his values; and, if the proper values are assigned to the short-period terms in comparing it with observation, the claim of Mr. Cowell's empirical terms of long period to represent the observations must stand or fall by the result. From 1750 onwards the discordances found by Mr. Nevill, who has applied a nine years average in order to eliminate errors in the short-period terms, do not exceed those found by Mr. Cowell himself. The one apparent exception, $+3''\cdot98$ in 1815, is clearly a misprint for $+2''\cdot98$. The weight to be attached to the earlier observations is a question which I do not feel qualified to discuss, but Mr. Nevill maintains that the solution fails entirely even for the observations between 1850 and 1900, which only means that the solution is not complete. Mr. Cowell regards the outstanding errors as errors of comparatively short period, and claims to have shown that when these are eliminated by a seventeen years average, his empirical terms will satisfy with rigour the requirements of the period 1750 to 1901.

Mr. Nevill, after constructing "Cowell Solution I," goes on to construct "Cowell Solution II," which only differs from "Cowell Solution I" in that it is based on the second formula quoted above from Mr. Cowell's paper as an alternative expression, containing different values for each of the secular terms and terms of very long period, but having the same total value as the first formula within the range of modern observations. Here, however, Mr. Nevill has, as has been seen, neglected to reduce these terms from Mr. Cowell's epoch (1826·1) to the epoch 1800·0, for which Mr. Nevill formulates them. Mr. Nevill's "Cowell Solution II" is therefore = "Cowell Solution I" $- 0''\cdot5 - 2''\cdot3$ T, where T is reckoned from 1800·0. But of this solution Mr. Nevill makes no further use.

Next, referring to the correction mentioned above as adopted by Mr. Cowell in *M.N.*, lxv. p. 273, Mr. Nevill proposes a third solution, which shall embody the corrected values for the secular terms, but he expresses doubt whether there is to be a proportionate change in the empirical term of long period, or whether that term should be left as expressed by Mr. Cowell in the second formula quoted above

$$+9''\cdot8\cos 50^\circ\, t - 7''\cdot2\sin 50^\circ\, t.$$

It is clear from this that Mr. Nevill has failed to grasp the significance of this second formula. As Mr. Cowell explains in *M.N.*, lxv. p. 53, the second formula is obtained by expanding the

first formula in powers of t, ascribing part of the coefficient of t^2 to secular acceleration, and making the corresponding corrections in the remaining secular terms and in the periodic term. The first of the two formulæ is that which, with the value for secular acceleration adopted in Newcomb's corrections to Hansen, and with a round number of degrees for the coefficient of t, will best agree with the observations. The second formula is that which will give the same result with the next round number of degrees (in this case 50) for the coefficient of t. In the first formula the secular acceleration determines the coefficient of t; in the second formula the secular acceleration and the other secular terms, with the coefficient and phase of the periodic term, are themselves determined by an arbitrary coefficient of t. It would be possible to construct any number of formulæ in this way which would all possess the same arithmetical value, but to take the periodic term from any one formula without the corresponding secular terms is to depart entirely from the principle of Mr. Cowell's investigation. It was therefore with justice that Mr. Nevill, in constructing "Cowell Solution III," made a change in the empirical term of long period proportionate to the change in the secular terms.

Mr. Nevill reduces the periodic term in Mr. Cowell's first formula to

$$+17''\cdot86 \sin \{0^\circ\cdot99[Y - 1850\cdot50] + 146^\circ\cdot9\}$$

and the corresponding term in his second formula to

$$+12''\cdot16 \sin \{1^\circ\cdot10[Y - 1850\cdot5] + 152^\circ\cdot1\},$$

where he afterwards substitutes for $152^\circ\cdot1$ the more correct value 153°.

For a value of secular acceleration intermediate between those corresponding to these two terms we get by simple interpolation

$$+15''\cdot0 \sin \{1^\circ\cdot05[Y - 1850\cdot50] + 150^\circ\}.*$$

Here Mr. Nevill gives $351^\circ\cdot4$ instead of 150°. This appears, however, to be only a clerical error. His detailed computations imply the correct value. But, as before, Mr. Nevill is led astray by Mr. Cowell's neglect to reduce his corrections to the secular terms to the epoch 1800·0, and the total expression for this solution therefore contains an error of

$$+2''\cdot6 - 1''\cdot5T - 2''\cdot8 + 0''\cdot4T.$$

"Cowell Solution III" is therefore = "Cowell Solution I" $- 0''\cdot2 - 1''\cdot1T$.

* The exact expression for the long-period term and corrections to the secular terms resulting from an assumed correction of $-2''\cdot2$ for secular acceleration, as calculated by the method described by Mr. Cowell in *M.N.*, lxv. p. 53, and reduced to the epoch 1800·0, is

$$-4''\cdot30 + 14''\cdot77 \sin\{1^\circ\cdot04[Y - 1850\cdot50] + 149^\circ\cdot7\}$$
$$+3''\cdot07 - 0''\cdot50T - 2''\cdot20T^2.$$

But Mr. Nevill, doubting whether Mr. Cowell may not after all have wished to combine his corrections to secular terms as given in *M.N.*, lxv. p. 273, quoted above, with his second formula for the long-period term, formulates a "Cowell Solution IV," in which these two are blended. This also omits the reduction to epoch of the secular terms. This solution therefore contains as the corrections to the secular terms

$$+2''\cdot6 - 1''\cdot5\mathrm{T} - 2''\cdot2\mathrm{T}^2$$

instead of

$$+5''\cdot7 - 0''\cdot7\mathrm{T} - 4''\cdot4\mathrm{T}^2$$

which would have made it = "Cowell Solution I." Then we have "Cowell Solution IV" = "Cowell Solution I" $- 3''\cdot1 - 0''\ 8\mathrm{T} + 2''\cdot2\mathrm{T}^2$. The solution, as has been seen, combines elements with no necessary connection from two independent formulæ, and any value it may possess is independent of Mr. Cowell's methods of investigation.

Curiously enough, this is the solution which Mr. Nevill finds in closest agreement with the observations. In order to reduce the discordance, he proposes a further correction of $-1''\cdot5$. We thus get

"Cowell Solution IV*" = "Cowell Solution I" $- 4''\cdot6 - 0''\cdot8\mathrm{T} + 2''\cdot2\mathrm{T}^2$.

Mr. Nevill has been at the pains to compute the tabular errors resulting from Solutions I, III, IV, IV* for every fifth year from 1630 to 1900. It will be observed that the differences between the tabular errors resulting from Solutions III, IV, IV* can in a large majority of instances be reduced to the errors of Solution I by applying the equations that I have given above. In the cases where this is not so, it seems probable that Mr. Nevill's arithmetic is at fault. It will be observed that these instances always break a run of differences.

The most successful of these solutions, according to Mr. Nevill's criterion, included the term of long period given in Mr. Cowell's second formula. Although this was a purely artificial term, Mr. Nevill declares that there can be little doubt that its argument is identical with the argument shown by theory to exist in the form

$$\sin\{3v - 7\mathrm{E} + 4\mathrm{M} + 326^\circ\cdot8\}$$

which can be written as

$$\sin\{1^\circ19(\mathrm{Y} - 1850\cdot50) + 153^\circ\cdot3\}.$$

This may have encouraged Mr. Nevill to retain this term.

Eventually combining "Cowell Solution IV*" with Mr. Cowell's corrections to terms of short period, Mr. Nevill finds a solution which he calls "Cowell" without further qualification;

and after comparing this with the observations 1851–1902 he discovers a new term of long period

$$-1''{\cdot}00 \sin \{3^\circ{\cdot}0[Y - 1850{\cdot}5]\},$$

by applying which to "Cowell" he obtains a "Cowell supplemented," which reduces the triannual mean discordances below a second of arc. Mr. Nevill then suggests a further period of about thirty-six years and two of about nine years to remove the outstanding inequalities.

But whatever value this solution may possess is clearly independent of the way in which it has been obtained, and it cannot fairly be called a supplement to Mr. Cowell's solution which was obtained by a strict mathematical method, contrasting markedly with the combination of errors that led Mr. Nevill to his final result.

1909 *September* 1.

Observations of Jupiter's Sixth, Seventh, and Eighth Satellites from photographs taken with the 30-inch Reflector at the Royal Observatory, Greenwich, in 1909.

(*Communicated by the Astronomer Royal.*)

The sixth, seventh, and eighth satellites of Jupiter have been under observation during the recent opposition of Jupiter with the 30-inch reflector, photographs having been obtained whenever possible. In all 27 photographs of Satellite VI, 7 photographs of Satellite VII, and 17 photographs of Satellite VIII have been secured between 1909 January 16 and May 20.

The positions of the satellites have been measured on the photographs taken with the reflector with reference to faint comparison stars (of eleventh or twelfth magnitude), symmetrically distributed about the satellites. The positions of these faint comparison stars were then measured relatively to the reference stars (of eighth to ninth magnitude) on photographs (with two exposures of 30^m or 40^m) taken with the Astrographic 13-inch refractor. The field, sensibly free from distortion, being much larger with this telescope than with the reflector, from 15 to 21 reference stars were available on each plate. As Jupiter moved slowly, it was possible to make one reference plate serve for several photographs, which were each referred to it. The constants of the reference plates were determined in the usual manner, all the stars on the plate given in the Astronomische Gesellschaft catalogues being used for this purpose. Right ascensions and declinations of

the satellites were then determined, and compared with the corrected tabular places of Jupiter after applying the corrections

in R.A. $+0^{s}\cdot163$, and Dec. $+1''\cdot14$

as determined below.

The G.M.T. is the arithmetical mean of the times of beginning and end of exposure.

SATELLITE VI.

Date and G.M.T.				Exposure.	Apparent R.A.			Apparent Dec.			Sat. VI—Jupiter. R.A.		Sat. VI—Jupiter. Dec.	
1909.	d	h	m	m	h	m	s	°	′	″	m	s	′	″
Feb.	12	12	53·5	49	10	56	35·79	+ 8	36	22·8	+2	27·18	+7	35·0
,,	13	13	16·1	90	10	56	3·88	8	39	23·3	2	22·37	7	39·3
,,	17	12	37·3	36	10	53	54·39	8	51	20·9	2	1·90	7	53·4
,,	18	12	37·2	90	10	53	20·58	8	54	23·5	1	56·20	7	56·1
,,	19	12	18·9	70	10	52	46·89	8	57	23·3	1	50·49	7	57·5
,,	20	12	36·8	38	10	52	12·14	9	0	29·1	+1	44·64	7	59·8
Apr.	7	8	30·7	43	10	27	50·46	10	49	46·5	−3	1·89	1	14·9
,,	7	9	11·0	10	10	27	50·00	10	49	47·5	3	1·89	1	13·4
,,	7	9	27·5	10	10	27	49·71	10	49	49·1	3	2·00	1	14·0
,,	8	9	10·1	90	10	27	29·86	10	50	57·4	3	6·01	0	58·2
,,	8	10	17·9	30	10	27	28·99	10	51	0·9	3	6·16	0	57·8
,,	9	9	5·2	73	10	27	10·88	10	52	1·3	3	9·64	0	41·1
,,	10	9	32·2	90	10	26	51·95	10	53	4·6	3	13·51	+0	25·7
,,	14	9	56·9	161	10	25	45·59	10	56	34·1	3	27·04	−0	35·1
,,	16	9	47·6	120	10	25	17·66	10	57	51·8	3	32·70	1	7·3
,,	16	11	35·3	70	10	25	16·73	10	57	54·8	3	32·84	1	8·1
,,	18	9	48·7	90	10	24	52·73	10	58	54·9	3	37·98	1	38·2
,,	20	9	30·8	120	10	24	31·54	10	59	42·6	3	42·38	2	7·3
,,	20	10	56·6	20	10	24	30·84	10	59	42·8	3	42·62	2	9·2
,,	21	11	38·5	30	10	24	21·20	11	0	0·3	3	44·68	2	24·7
May	6	9	20·1	20	10	23	39·08	10	56	27·7	4	0·11	5	44·7
,,	7	9	48·5	63	10	23	42·80	10	55	42·7	4	0·19	5	55·9
,,	8	9	58·0	100	10	23	47·23	10	54	54·4	4	0·21	6	6·8
,,	10	11	9·5	78	10	23	58·82	10	53	3·3	3	59·80	6	29·1
,,	11	10	36·6	120	10	24	5·43	10	52	5·3	3	59·51	6	39·1
,,	18	10	15·0	90	10	25	13·99	10	43	32·4	3	54·66	7	40·6
,,	20	9	58·8	30	10	25	40·38	+10	40	33·5	−3	52·23	−7	57·1

Apr. 9. Sky became hazy as exposure proceeded.
May 11. Very diffused.

SATELLITE VII.

Date and G.M.T.				Exposure.	Apparent R.A.			Apparent Dec.			Sat. VII—Jupiter. R.A.		Sat. VII—Jupiter. Dec.	
1909.	d	h	m	m	h	m	s	°	′	″	m	s	′	″
Feb.	12	12	53·5	49	10	58	11·89	+ 8	34	58·3	+4	3·28	+ 6	10·5
,,	13	13	16·1	90	10	57	42·48	8	38	34·9	4	0·97	6	50·9
,,	18	12	37·2	90	10	55	12·50	8	56	36·0	3	48·12	10	8·7
,,	19	12	18·9	70	10	54	41·65	9	0	13·6	3	45·25	10	47·8
,,	20	12	36·8	38	10	54	9·68	9	3	57·2	+3	42·18	11	27·9
Apr.	16	11	35·3	70	10	28	16·96	11	32	38·1	−0	32·61	33	35·2
,,	20	9	30·8	120	10	27	23·93	+11	35	23·0	−0	49·99	+33	33·1

SATELLITE VIII.

Date and G.M.T.				Expo-sure.	Apparent R.A.			Apparent Dec.			Sat. VIII—Jupiter. R.A.		Sat. VIII—Jupiter. Dec.		Tab.—Obs. R.A.	Tab.—Obs. Dec.
1909.	d	h	m	m	h	m	s	°	′	″	m	s	′	″	s	″
Jan.	16	13	14·7	120	10	56	46·77	+7	40	43·2	−6	21·63	+13	49·5	+0·16	+1·7
,,	16	15	3·1	65	10	56	45·67	7	40	46·6	6	21·83	13	46·0	+0·14	+3·2
,,	19	13	31·8	140	10	55	59 27	7	44	18·2	6	30·04	12	31·3	+0·13	+1·4
Feb.	12	11	35·2	70	10	46	47·88	8	29	43·5	7	22·17	1	5·1	+0·33	+0·6
,,	13	11	29·4	90	10	46	19·89	8	32	5·6	7	23·61	+ 0	34·5	+0·23	+1·2
,,	15	12	21·7	60	10	45	21·55	8	37	3·3	7	26·68	− 0	25·7	+0·32	+0·1
,,	17	11	25·8	60	10	44	24·54	8	41	53·8	7	29·34	1	24·7	+0·33	0·0
,,	18	10	51·5	90	10	43	55·78	8	44	19·1	7	30·68	1	54·9	+0·42	+0·8
,,	20	11	17·1	90	10	42	56·16	8	49	23·5	7	32·93	2	55·7	+0·26	+0·9
Apr.	7	8	30·7	43	10	23	27·08	10	25	33·1	7	25·28	22	58·5	+0·52	−0·7
,,	8	9	10·1	90	10	23	12·26	10	26	39·4	7	23·62	23	19·8	+0·32	−0·5
,,	14	9	56·9	161	10	21	58·74	10	31	49·8	7	13·89	25	19·4	+0·19	+0·7
,,	16	9	47·6	120	10	21	39·88	10	33	4·2	7	10·49	25	54·9	+0·32	−0·8
,,	18	9	48·7	90	10	21	23·93	10	34	1·5	7	6·78	26	31·6	+0·31	−0·3
May	7	9	48·5	63	10	21	18·88	10	30	8·0	·6	24·11	31	30·6	+0·01	−0·6
,,	8	9	58·0	100	10	21	25·62	10	29	16·7	6	21·82	31	44·5	+0·28	−0·6
,,	10	10	45·5	93	10	21	41·98	+10	27	21·1	−6	16·53	−32	12·1	+0·25	−0·7

Jan. 19. Extremely faint.
Apr. 7. Extremely faint and diffused.
,, 14. Unsatisfactory photograph. Image elongated.
May 7, 8. Excessively faint and difficult to measure.
,, 10. Very diffused and difficult to measure.

The tabular place of the Eighth Satellite has been taken from the Ephemeris by Messrs. Cowell, Crommelin, and Davidson, published in *M.N.*, vol. lxix. No. 5.

Errors of Tabular Place of Jupiter.

The positions of the satellites given above depend on the positions of certain stars taken from catalogues of the Astronomische Gesellschaft, and will be affected by the mean error in the places of these stars. To eliminate this it is necessary to determine the position of Jupiter referred to the same stars.

For this purpose a number of photographs of Jupiter were taken with the 26-inch refractor, using the occulting shutter. By this means good measurable images of Jupiter were obtained, together with sufficiently exposed images of the reference stars. The field of the 26-inch on a 16 cm. plate is one square degree, and four or six comparison stars in this area were measured together with Jupiter. The adopted places of these six stars were deduced from measures made on the Astrographic reference plates, the constants of the reference plates being, as above mentioned, derived from all the available stars in the Astronomische Gesellschaft catalogues. The places of the four or six stars, and therefore the deduced place of Jupiter, will be affected by the mean systematic error of all the catalogue stars on the reference plates, and will thus be comparable with the deduced places of the satellites.

Seven photographs were selected for measurement. Three or four images of Jupiter and of each of the stars were measured on each plate in the Astrographic micrometer, and the following are the results obtained :—

Errors of N.A. Tabular Place of Jupiter.

1909.	Tab.—Obs. R.A.	Tab.—Obs. Dec.
	s	"
Mar. 31	−·22	−1·5
,, 31	−·21	−1·7
Apr. 5	−·15	−1·1
,, 8	−·13	−1·4
,, 20	−·13	−0·8
May 6	−·15	−0·6
,, 15	−·15	−0·9
Mean	−·163	−1·14

Corrections for these mean errors have been applied to the tabular place of Jupiter, as already stated.

Royal Observatory, Greenwich :
1909 *August* 6.

Shower of ζ Draconids. By W. F. Denning.

There is a well-defined radiant a few degrees S.E. of ζ Draconis which becomes active at various times during the year, and is notably so at the end of the third week in August, when it supplies meteors which are brilliant if not very abundant. The position is at 263°+62°. I observed a fine 1st. mag. on August 21 this year crossing the star cluster in Perseus and directed from this radiant. On the same day of the month in previous years I remembered to have recorded very bright meteors from it.

I have consulted my observations and formed a table of the more conspicuous objects presumably directed from this radiant of Draconids. I have registered hundreds of ordinary shooting stars from the same stream. It appears to exhibit an intermittent display at various periods and may possibly be visible all the year round. It has been chiefly noticed in January, March, April, July, August, October, November, and deserves much further observation as a prominent example of stationary radiation.

From single observations of meteors it is impossible to be absolutely certain of correctness in allotting the radiants. The observed path of an object, when carried back in the line of flight, usually crosses several radiants, and it is only after long experience and due consideration of all the details which can assist the judgment that proper positions can be assigned. The direction of flight is in itself an insufficient guide; it is, however, a good "dividing rod" taken in combination with the meteor's aspect, apparent velocity, length of path, streak, train, etc. In cases where all these things are allowed proper weight in attributing the centres of divergence, a person should, I believe, be correct in three cases out of four.

The long-continued or intermittent shower near ζ Draconis is of special interest as being near the pole of the ecliptic and visible in our latitude at any season of the year.

The fireball of August 21, 1887, was also observed by Mr. D. Booth at Leeds, and the radiant derived from a projection of the apparent path recorded at Bristol and Leeds was found to be at 264°+61.° The radiant of the fireball of 1893 October 1 was at 265°+65°.

Bright ζ Draconids observed at Bristol.

			Path					
			From		To		Length.	
	h m	mag.	°	°	°	°	°	
1909 Mar. 17	9 4	1	115	+ 19	108	− 9	29	*v v* slow T
1887 28	12 53	♃	330	50	345½	+40	14½	R
1893 Apr. 20	13 26	>1	292	67	307	67	6	R K
1874 20	11 48	1	280	26	286	+13	14	R
1880 30	10 0	1	233½	+ 8	227	−10	19	not R K

Bright ζ Draconids observed at Bristol—continued.

		h	m	mag.	Path From °	°	Path To °	°	Length. °	
1886	May 5	14	40	>1	315	+85½	33	+86	6	*v v* R
1906	June 18	12	13	♀	276	12	277¼	4	8	R T
1903	29	13	30	♃	333	31	339	21	11	*v* slow yell.
1891	July 2	10	49	1	183	38	167	19	23½	R
1877	4	9	41	1½	203	39	190	27	16	*v v* R
1877	7	12	17	1	310	43	318	34	11	slow K
1880	29	10	15	1	246	21	245¼	15	6	not R K
1880	,,	10	44	♃	22	86	55	76	11	R in haze
1886	Aug. 2	10	35	1	252	66	248	67	2	R
1878	10	11	36	1	340	61½	354	55½	10	R T
1881	21	8	50	>♀	200	48	178	29	25	slowish
1887	,,	11	2	♀	230	61	218	59	6	slow K
1909	,,	10	19	1	31	59½	38½	49	12	*v* slow T
1887	23	13	35	1	237	68½	224	69½	5	*v* slow
1900	26	11	32	1	348	42½	1	28	17	K 7 sec.
1891	28	8	22	>1	160	74	136	67	10½	*v* slow yell.
1877	Sept. 7	10	43	1	160	59	145	49	13	slow
1908	Oct. 1	7	44	1	270	86	82	83	11	*v* slow
1874	31	8	23	1	169	77	137	60	19	*v* slow
1877	Nov. 1	8	9	>1	20	66	39	45	23	slow yell. T.
1877	7	9	12	>1	220	+73	180	+74	11	slowish.

v, very ; R, rapid ; T, train ; K, streak.

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An asterisk (*) indicates that the work is an excerpt.

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MONTHLY NOTICES

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